Variability in Intake and Dehydration in Young Men During a Simulated Desert Walk

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Voluntary dehydration was examined in young unacclimatized men walking under simulated desert conditions. Thirty-three subjects (20–33 years) walked on a treadmill (4.82 km · h⁻¹, 5% grade) for 30 min · h⁻¹ for 6 h in a hot environment (40°C db/ 26°C wb, 4.02 km · h⁻¹ windspeed). Cool (15°C) water was provided *ad libitum* in canteens. Because thirst is stimulated and drinking should occur at about 2% body weight loss as body water, we used this criterion to identify two groups of individuals. Individuals who maintained body weight (BW) loss at less than 2% (0.44–1.88%) were defined as avid drinkers (D, n = 20) and those who exceeded the 2% BW loss (2.07–3.51%) despite the continual availability of cool (15°C) water were called reluctant drinkers (RD, n = 13). RD consumed 31% less water (2.05 ± 0.14 L) than D (2.98 ± 0.12 L), and this resulted in a significantly greater BW loss in RD (2.65 ± 0.11%) than D (1.16 ± 0.11%). However, the only statistically significant differences in plasma indices of dehydration were the higher final plasma Na⁺ and protein levels in RD. Rectal temperature was higher in the RD, whereas final heart rates were unaffected. In the current study, about 40% of the young adult male subjects were reluctant to drink, and thus voluntarily dehydrated even when given cool water *ad libitum* during intermittent exercise in the heat. The reduced intake of these reluctant drinkers may be critical in predisposing them to increased risk of dehydration and heat injury.

MEN LIVING and working for prolonged periods in hot environments nearly always become dehydrated, since they rarely voluntarily drink sufficient fluids to replace quantities lost in sweat. Adolph (1) noted that daily body weight losses of 2 to 3% may be commonplace when working in the desert, even if water is plentiful and palatable. Varying degrees of dehydration ranging from 1.5% to 7% loss of body weight have been reported in both field and laboratory settings in men working in hot climates (1,3,8,11,13,17,19), as well as in marathoners running in temperate climates (14). Rothstein *et al.* (17) concluded that the phenomenon of voluntary dehydration results from an inadequacy of the thirst mechanism to stimulate sufficient drinking for complete rehydration.

Holmes and Gregerson (10) reported a marked variability among dogs in the drinking response both as to timing and quantity drunk. The authors concluded that the large sample (40 dogs) enabled them to observe a range of drinking patterns in response to an injection of hypertonic NaCl. This wide range of drinking behavior suggests significant inter-individual variability in the pattern of drinking responses to a single stimulus.

These latter findings prompted us to assess dehydration in young adults during treadmill exercise under desert conditions when cool water was available *ad libitum*. Unlike previous studies (1,9,13,17,19), we measured fluid consumption and the extent of voluntary dehydration in a sample population of 33 young adult males exercising at a constant work level under controlled environmental conditions. Water at 15°C was chosen because water temperatures ranging from 10° to 15°C have been shown to be preferred by humans when large quantities must be drunk to reduce dehydration (1,4,18,19). Additionally, the impact of dehydration on several physiological responses was assessed.

METHODS

Subjects: Thirty-three healthy unacclimatized male volunteers were recruited based on age, inexperience with water balance studies, and subject availability. Physical characteristics (mean ± S.E.M.) of the group

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were: 179.6 ± 1.5 cm height, 77.13 ± 1.82 kg weight, and 23.6 ± 0.5 yr (range = 20–33 years). Each subject was informed of the test design and procedures, but the importance of the *ad libitum* fluid intake and body weight measurements was not emphasized.

Experimental design: The study was conducted in a climatic chamber between mid-November and February; thus, none of the subjects was naturally acclimatized to the heat. Chamber conditions were maintained at 40°C dry bulb and 30–40% R.H. with a 4.02 km • h^{-1} windspeed providing a WBGT of about 30°C.

Subjects wore shorts, socks, underpants, and sneakers, and walked on a treadmill (4.82 km • h^{-1}, 5% grade) for 30 min of each hour. During the remaining 30 min of each hour, subjects were sedentary; thus, at the end of each 6-h trial, each subject had walked 14.5 km and climbed 724 m.

Cool (15°C) tap water (municipal water supply, Natick, MA) treated with military-issue iodine (I_2) disinfectant tablets (16 mg • L^{-1}) to simulate normal field pick-up water was provided during the 6 h of intermittent exercise. Water was provided *ad libitum* in coded canteens placed within comfortable reach of each subject. Voluntary dehydration and fluid balance were assessed through analyses of water intake, body weight loss, plasma electrolyte changes, and heat strain indices.

Measurements: Following breakfast at 0700 hours, subjects voided a pretest urine sample for determining initial hydration status by specific gravity. Initial nude body weight (Sauter balance, ±10 g), clothed-instrumented weight, age, and height were recorded. Clothed-instrumented body weights were taken prior to the start of the first 30 min of exercise, and were repeated at the end of each subsequent 30-min walk and recovery period. Fluid intake was measured by weighing (Sartorius, ±1 g) the canteens at each 30-min interval, or when canteens were refilled. Lunch consisting of Army rations (Meal, Ready to Eat) was provided during the third recovery period (2.5–3.0 h).

After entering the climatic chamber, subjects remained standing for 20 min after which a base line (Pre-Ex) venous blood sample was drawn from a superficial arm vein. After the sixth walk (6 h), a final blood sample (Post-Walk 6) was obtained. Hematocrit (Hct) was measured using the microhematocrit technique and hemoglobin was determined by the cyanmethemoglobin method. The change in plasma volume (Post-Walk 6 vs. Pre-Ex) was calculated (7). Serum was analyzed for electrolytes (flame photometry), osmolality (freezing point depression) and total protein (refractometer).

Subjects were fitted with standard ECG electrodes, a rectal probe (inserted to a depth of 10 cm), and three skin thermocouples (chest, calf, and arm) from which heart rate, rectal temperature, and mean weighted skin temperature were continuously monitored.

Group comparison *t*-tests and ANOVA's were performed to evaluate the effects of drinking on the physiological responses to exercise in the heat. The null hypothesis was rejected at $p < 0.05$. Some of the body weight loss and fluid intake data were presented at a symposium (21).

RESULTS

All of our subjects began the study in a euhydrated state: breakfast beverages were provided, specific gravities on post-breakfast urine samples indicated adequate hydrational status (U_{SG} = 1.024 ± 0.001), and each subject consumed an additional 250 ml of water about 30 min before the first walk.

During the entire 6-h test interval, the 33 subjects consumed (mean ± S.E.M.) 2.61 ± 0.12 L of cool water yet still lost 1.75 ± 0.15% of their initial body weight. As shown in Fig. 1, marked inter-individual variability was noted in both the amount of body weight lost and the amount of cool water consumed during the 6 h. Individual 6-h body weight deficits (Fig. 1, lower panel) ranged from 0.44% to 3.51% of initial body weight, while *ad libitum* fluid intake (Fig. 1, upper panel) ranged from 1.04 L to 3.81 L.

Since a 2% loss of initial body weight has generally been accepted as a threshold for thirst stimulation (1,8,17,19), we chose this criterion for identifying the 20 individuals who maintained body weight losses less than 2% as avid drinkers (D) and those 13 subjects who were reluctant to drink and lost more than 2% of their initial body weight as reluctant drinkers (RD). No statistical differences in physical characteristics (Table I), Pre-Ex urine specific gravity, Pre-Ex heat strain indices (Table II), or Pre-Ex serum variables (Table III) were found between D and RD.

Mean 6 h body weight losses for the D and RD were 1.16 ± 0.11% and 2.65 ± 0.11%, respectively. The greater weight deficit in RD was apparent even within the first 30 min ($p < 0.05$) (Fig. 2, upper panel). The increased dehydration observed in the 13 RD was due to insufficient water intake since significant differences in consumption ($p < 0.05$) were observed during the first 30-min walk (Fig. 2, lower panel), as well as the entire 6-h experimental interval (2.05 ± 0.14 L RD vs. 2.98 ± 0.21 L D, $p < 0.001$).

Exercise in the heat elicited significant changes in heat strain indices (Table II) measured at the end of Walk 6 and blood variables (Table II and III) measured 20 min Post-Walk 6 in both groups. Significant differences between the two groups were seen in the higher T_{re} (Table II, $p < 0.05$), plasma proteins ($p < 0.01$) and plasma Na^+ (Table III, $p < 0.05$) in RD at the end of 6 h.

DISCUSSION

Our study assessed the variability of fluid consumption and voluntary dehydration and their impact on several physiological variables in a population of 33 unacclimatized young adult men during recurrent exercise in a desert-like environment. Two unique findings emerged from this study: 1) striking variability in both fluid intake and therefore body weight loss in young men when exercising at similar work levels; and 2) 39% of these subjects were reluctant to drink and lost 2.65% of their initial body weight during the 6 h despite the continuous availability of cool (15°C) water. The differences in percent body weight loss (Fig. 2, upper panel) and fluid intake (Fig. 2 lower panel) between D and RD

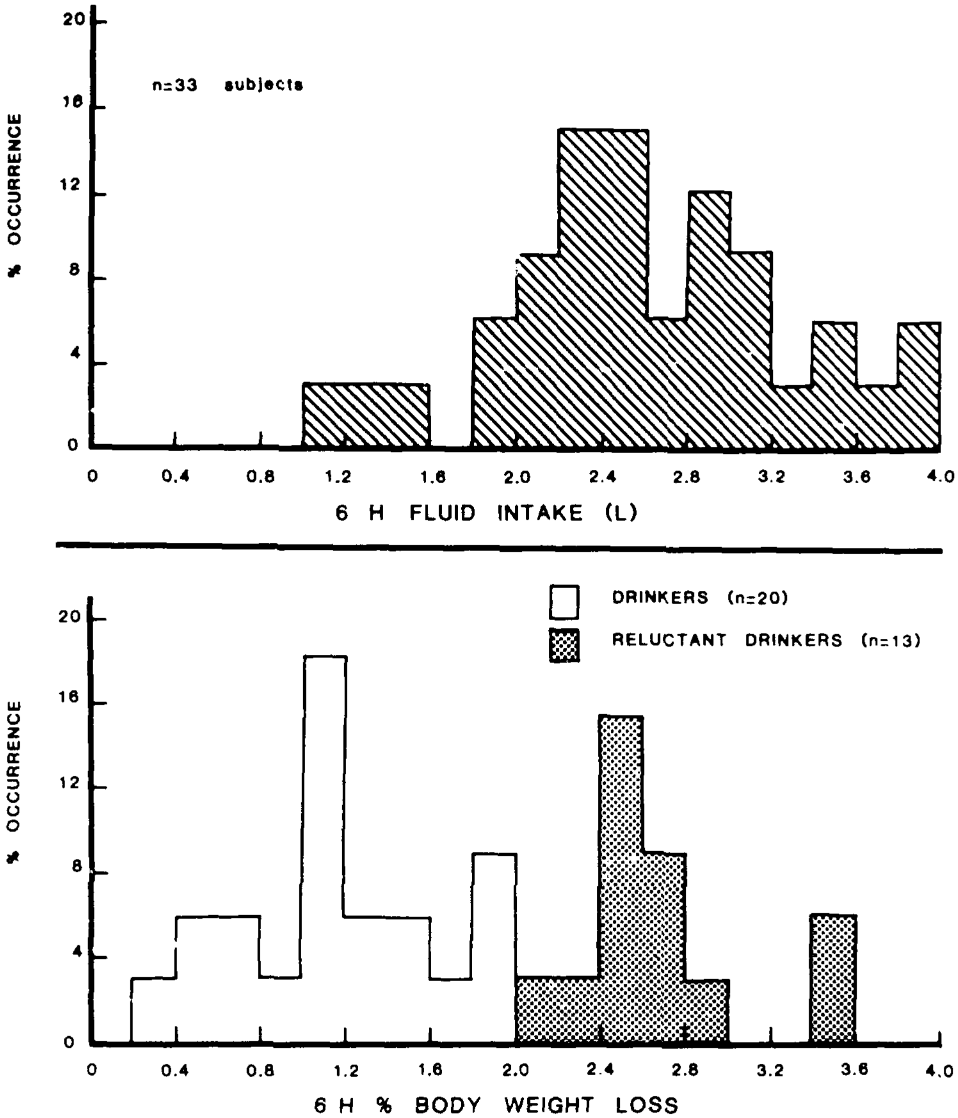

Fig. 1. Frequency distribution of 6-h fluid intake in liters (upper panel) and of 6-h percent body weight loss (lower panel) in 33 subjects drinking cool (15°C) water.

were apparent as early as the first 30-min walk and increased with time. Individual differences in fluid consumption (3.7-fold) and percent body weight loss (8-fold) were observed by the end of 6 h. The extent of voluntary dehydration which can occur while working in a hot environment is better described by the ranges of body weight loss and fluid consumption than by average values.

Rothstein *et al.* (17) noted body weight losses varying

TABLE I. SUBJECT PHYSICAL CHARACTERISTICS.

	Age (yr)	Weight (kg)	Height (cm)	Pre-Ex Urine Specific Gravity
Drinkers	23	78.6	181	1.024
	± 1	± 2.4	± 2	± 0.001
Reluctant Drinkers	24	74.9	177	1.023
	[illegible]	± 2.9	± 2	± 0.001

Values are mean ± S.E.M. for 20 drinkers and 13 reluctant drinkers. All values are p = ns.

from 1.5 to 5.2% in men marching or operating equipment for as few as 3.5 h under warm field conditions. Inadequate fluid intake during 3.5 to 6 h of intermittent treadmill exercise resulted in reports of weight losses ranging from 0.5 to 3.5% (1,3,6,9,11,13,17,19), and deficits up to 10% have been documented in marathoners (14). While these previous studies did not examine the extent of variation in voluntary dehydration within a given subject population or under constant environmental and/or work conditions, intersubject variability in the drinking response to a constant stimulus with respect to both timing and amount consumed has been reported in both humans (12) and dogs (10). Holmes and Gregerson (10) reported that their large sample size enabled them to observe significant differences in drinking patterns between subjects, and also remarkable intra-individual consistency.

We observed that D rehydrated 76 ± 2% (range = 49–95%) whereas the RD rehydrated only 50 ± 2% (range = 31–59%) during the 6 h of intermittent walking. The lower fluid intake in RD contributed to the significant differences in weight loss since 6 h sweat

TABLE II. EFFECT OF FLUID INTAKE ON HEAT STRAIN INDICES.

	T_{re} (°C)	T_{sk} (°C)	HR (bpm)	Hct (%RBC)	Total Protein ($g \cdot 100\ ml^{-1}$)	ΔPV (%)
Drinkers (n = 20)						
Pre-Ex	36.99	35.3	84	43.2	7.3	—
	± 0.04	± 0.1	± 3	± 0.6	± 0.1	
Post-Walk 6	37.97*	34.9	131*	43.2	7.6*	0.3
	± 0.07	± 0.3	± 3	± 0.5	± 0.1	± 1.1
Reluctant Drinkers (n = 13)						
Pre-Ex	37.01	35.2	82	42.4	7.4	—
	± 0.04	± 0.1	± 3	± 0.8	± 0.1	
Post-Walk 6	38.18*#	34.6*	135*	42.7	8.3*#	3.4
	± 0.06	± 0.2	± 3	± 0.8	± 0.2	± 1.6

Values are means ± S.E.M.
T_{re}, rectal temperature; T_{sk}, mean weighted skin temperature; HR, heart rate; Hct, hematocrit, %ΔPV, change in plasma volume.
* $p < 0.05$ for preexercise vs. walk 6 or post-walk 6.
# $p < 0.05$ for drinkers vs. reluctant drinkers.

losses (4.08 ± 0.10 L) were nearly identical for the two groups. Earlier experiments in our laboratory yielded average rehydrations of 60% (11) and 80% (3) for sweat losses of 3.92 L and 3.4 L, respectively. Although adequate hydration is instrumental in maintaining heat balance (1,6,8,13,20), men working in the heat rarely replace more than two-thirds of the water lost in sweat. Man requires at least 30 min to accomplish 80% of total rehydration (1,17), and during the first 15–20 min, drinking is copious (17). Rolls and coworkers (16) reported that following 24 h of fluid deprivation, 65% of the total intake during the first hour was consumed in the initial 2.5 min. In comparison, Sohar *et al.* (19) recommended at least 20 min for adequate rehydration between work bouts. The mechanisms regulating the duration and amount of fluids drunk in response to dehydration are not known, and probably differ quantitatively between species (1,15,16).

Adolph and coworkers (1) reported that soldiers who maintained hydration via forced drinking performed better than those who drank *ad libitum*. Many studies have shown the detrimental effects of dehydration; 2 to 5% loss of body weight can cause lassitude, apathy, anorexia, and reduced work performance (1,13,19,20) concomitant with elevations in core temperature, heart rate, and risk of heat injury (1,3,6,8,13,19,20). Although not statistically significant, the group of reluctant drinkers had a greater loss of plasma volume than the avid drinkers (Table II). In both of our groups, we observed increases in heart rate and rectal temperature which, as previously noted (6,8,20), were in proportion to the level of dehydration. Our data show that for each percent of body weight lost, heart rate rose 6 bpm and rectal temperature increased 0.05°C. These modest differences are probably not surprising for the moderate level of dehydration elicited by this study. However, when considering individuals with the greatest and lowest dehydration, these differences are magnified. For example, the best of our D had significantly less body weight loss (0.44%) and lower maximal T_{re} (37.93°C) and HR (116 bpm) than the [illegible]t of our RD who lost 3.51% of his body weight a[illegible]fested a maximal T_{re} of 38.51°C and HR of 150 bp[illegible]

No differences in physical characteristics, pre-exercise thermoregulatory indices, and pre-exercise plasma variables were noted between the two groups, as

TABLE III. EFFECT OF FLUID INTAKE ON SERUM CLINICAL VARIABLES.

	P_{Osm} ($mOsm \cdot kg\ H_2O^{-1}$)	P_{Na^+} ($mEq \cdot L^{-1}$)	P_{K^+} ($mEq \cdot L^{-1}$)
Drinkers (n = 20)			
Pre-Ex	289	141	4.4
	± 1	± 1	± 0.1
Post-Walk 6	289	140*	4.6*
	± 1	± 1	± 0.1
Reluctant Drinkers (n = 13)			
Pre-Ex	288	144	4.3
	± 1	± 2	± 0.1
Post-Walk 6	291	145#	4.5*
	± 1	± 2	± 0.1

Values are mean ± S.E.M.
P_{Osm}, plasma osmolality; P_{Na^+}, plasma sodium concentration; P_{K^+}, plasma potassium concentration.
* $p < 0.05$ for pre-ex vs. post-walk 6
# $p < 0.05$ for drinkers vs. reluctant drinkers.

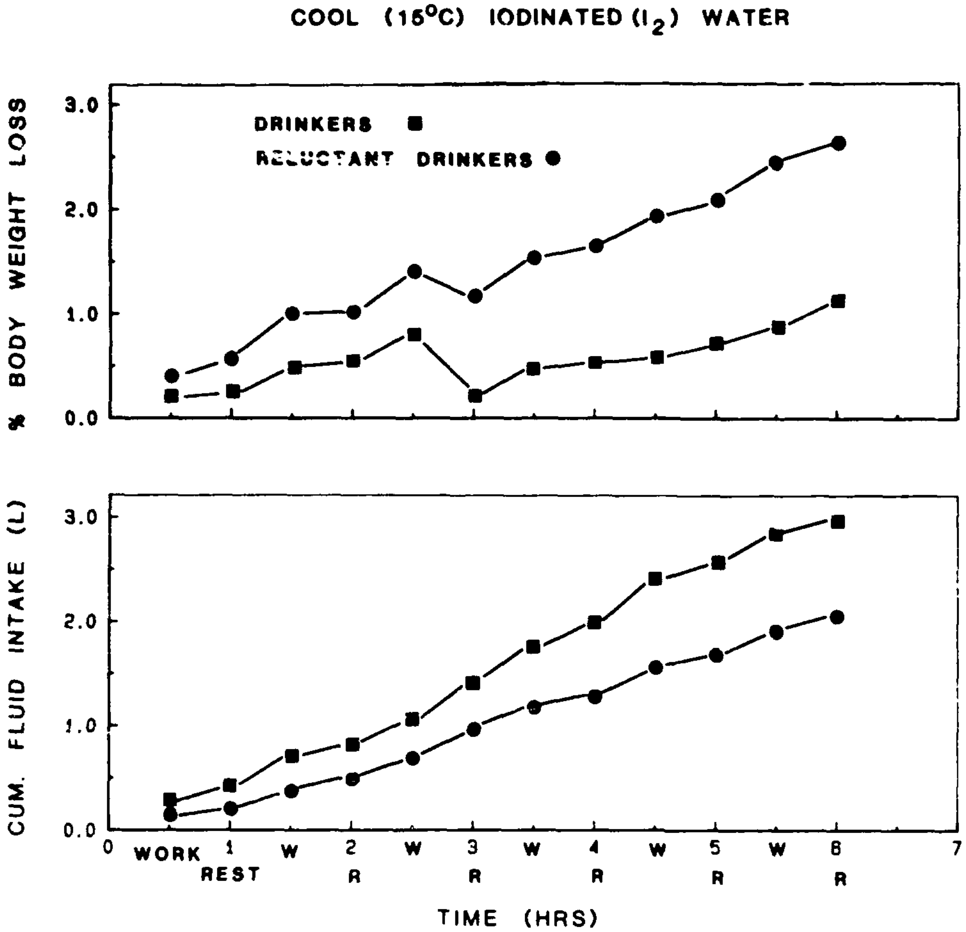

Fig. 2. Cumulative percent body weight loss (upper panel) and cumulative fluid intake in liters (lower panel) of drinkers and reluctant drinkers consuming cool (15°C) water.

shown in Tables I, II, and III. Sweat loss was not significantly affected by the modest levels of dehydration observed in this and previous studies (3,6,8,11). The 6 h sweat losses were not different between the two groups and were independent of dehydration level in the range of 0–3.5% body weight loss. Also, no differences in mean weighted skin temperatures were seen between the two groups (3). We conclude that there are no differences in any of the physiological or physical traits examined in this study to distinguish the reluctant drinker from an individual that avidly drinks.

An unresolved issue is the incomplete rehydration most notably seen in the individuals reluctant to drink despite marked fluid deficits. Several reasons for the different drinking behaviors in our avid and reluctant drinkers may include perception of mouth dryness and taste (2,11,12,15,16,18), perception of thirst (1,2,12,15,16,18,19), degree of gastric distention (2,15,16), hot weather experience, background, and tolerance to fluid deprivation (1). The backgrounds and hot weather experience of our two groups were similar. Because we did not measure the subjects' thirst ratings, mouth dryness, or discomfort, the contribution of a lack of thirst or other oropharyngeal stimulus to the current results is unknown.

Cabanac (5) noted that a stimulus can produce either pleasant or unpleasant sensations depending on an individual's internal state. Sandick and coworkers (18) reported that preference for cooler drinking water temperature is significantly enhanced by exercise. An increased preference for cold water during exercise in a hot environment most probably due to hyperthermia was reported by Hubbard and coworkers (11). Moreover, these investigators demonstrated that palatability factors can enhance pleasant sensations (11). A reduction in both the pleasantness of water and the intake during the course of rehydration was also shown by Rolls *et al.* (16). Potential differences between the avid drinkers and reluctant drinkers may be perception of temperature, taste, and change in preference during the course of the 6 h of intermittent exercise.

In summary, this study demonstrated marked variability in fluid intake and dehydration in adult men working intermittently in a hot climate. Only 20 of the 33 men consumed sufficient fluids to maintain their hydration at less than a 2% body weight loss during the 6 h. Test subjects who drank less water had greater fluid deficits and consequently higher exercising rectal temperatures and heart rates.

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of the authors and should not be construed as official Department of the Army policy, position, or decision, unless so designated by other authorizing documentation. Human subjects participated in this study after giving their informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on use of volunteers in research. Citations of commercial products in this report do not constitute an official Department of the Army endorsement or approval of the products or services of the organizations.

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